

A comprehensive study of the reaction $\gamma d \rightarrow \pi^0 d$ above 500 MeV

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Introduction

- We present a measurement of the reaction $\gamma d \rightarrow \pi^0 d$ at photon energies between 0.5 and 2.0 GeV and pion CM scattering angles between 50° and 150°.
- The measurement was done with the CLAS detector in Hall B at TJNAF.

Introduction

- $\gamma d \rightarrow \pi^0 d$ is a high momentum transfer nuclear reaction at specific kinematics.
- Good tool to study reaction dynamics at short distances:
 - Transition between meson-nucleon and quark-gluon degrees of freedom.
 - Non-trivial few-step rescattering mechanisms, such as intermediate η rescattering.

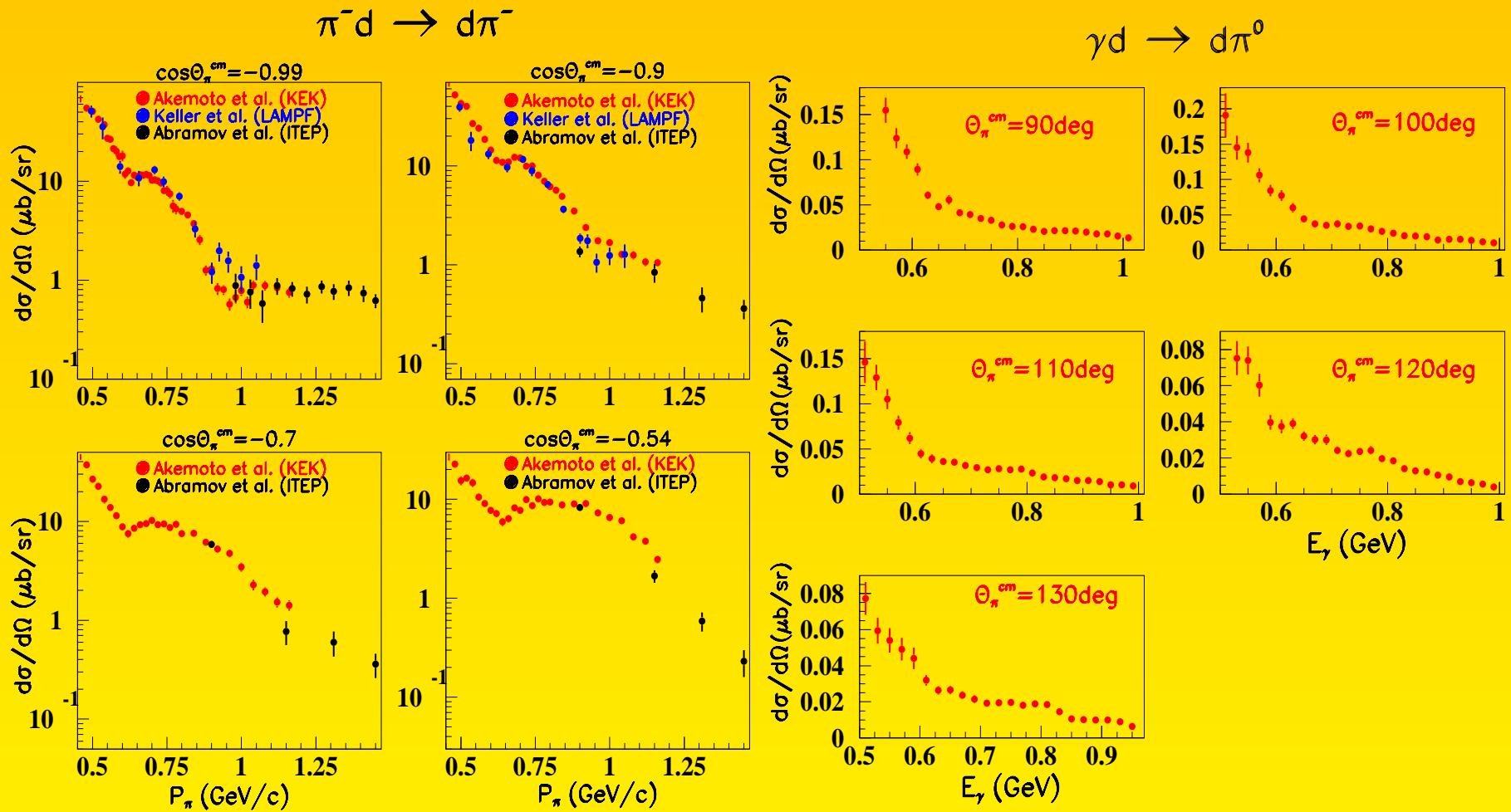
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Physics Motivation: intermediate η rescattering

- Unpolarized cross sections for $\gamma d \rightarrow p\pi^0 d$ from Imanishi et al. (Phys. Rev. Lett. 54, 2497(1985)), show an enhancement in the energy dependence around $E_\gamma = 0.7$ GeV at pion CM angles above 120° .
- Similar enhancement around beam momentum of 0.7 GeV/c is observed in the excitation functions of backward πd elastic scattering.

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Physics Motivation: intermediate η rescattering



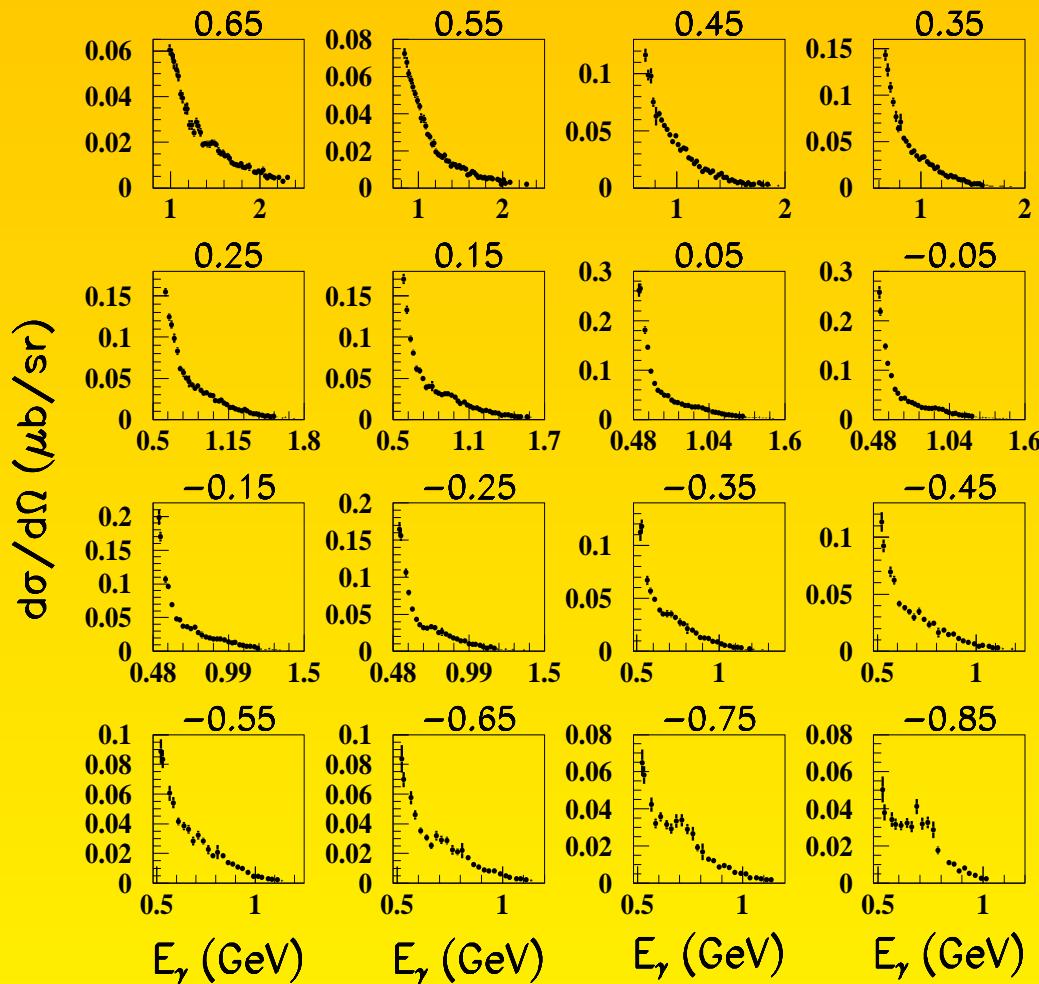
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Physics Motivation: intermediate η rescattering

- Existence of a structure around 0.7 GeV real?
- To study its behavior at various kinematics: CLAS data extend to larger pion CM angles.

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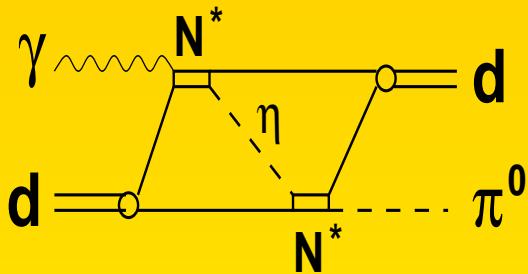
CLAS preliminary excitation functions for $\gamma d \rightarrow \pi^0 d$



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Physics Motivation: intermediate η rescattering

- The observed structure can be explained in terms of a contribution from η formation and rescattering via S_{11} excitation in the intermediate state.



- Fits to the CLAS data in order to determine the relative magnitude of the above subprocess.
- Interference with the background enhances the signal.

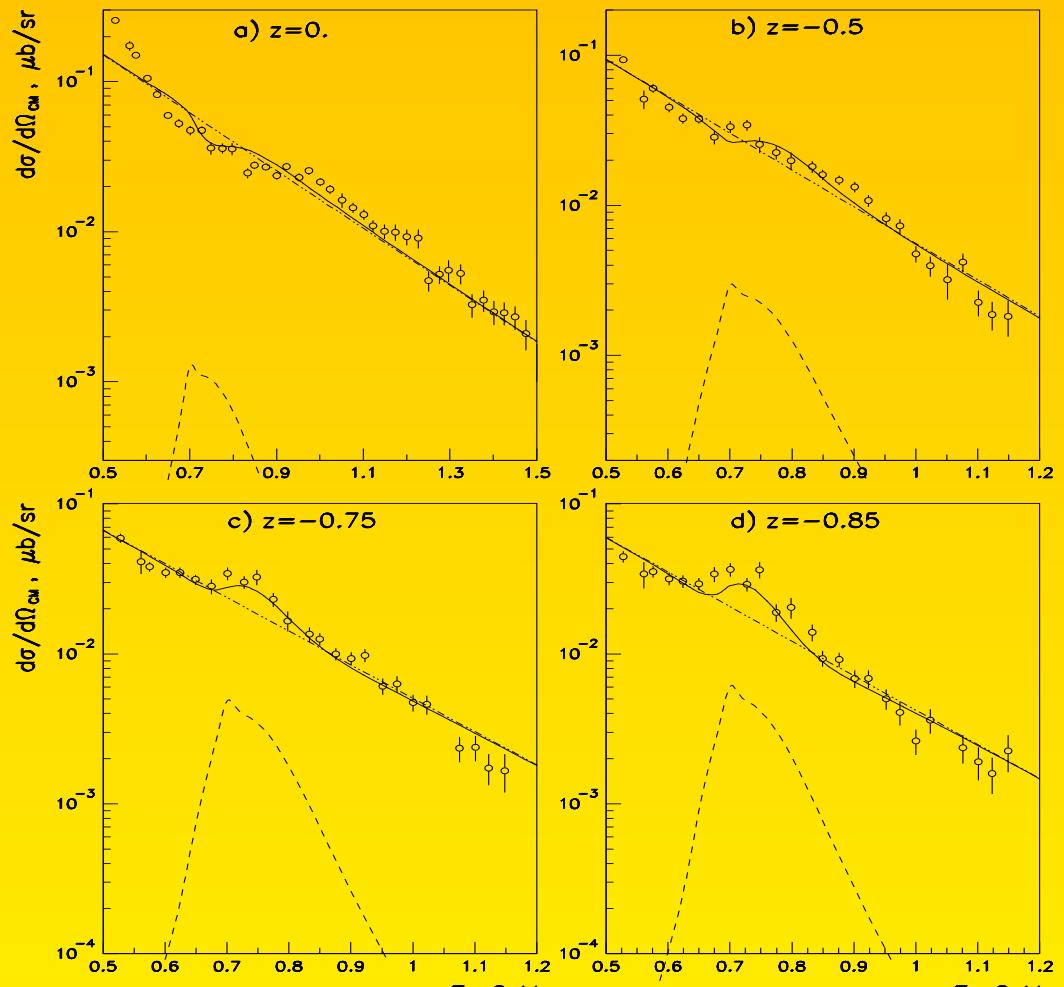


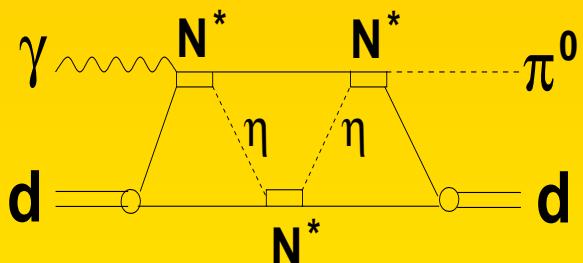
Fig.2

A.E. Kudryavtsev *et al.*, Phys. Rev. C71, 035202 (2005)

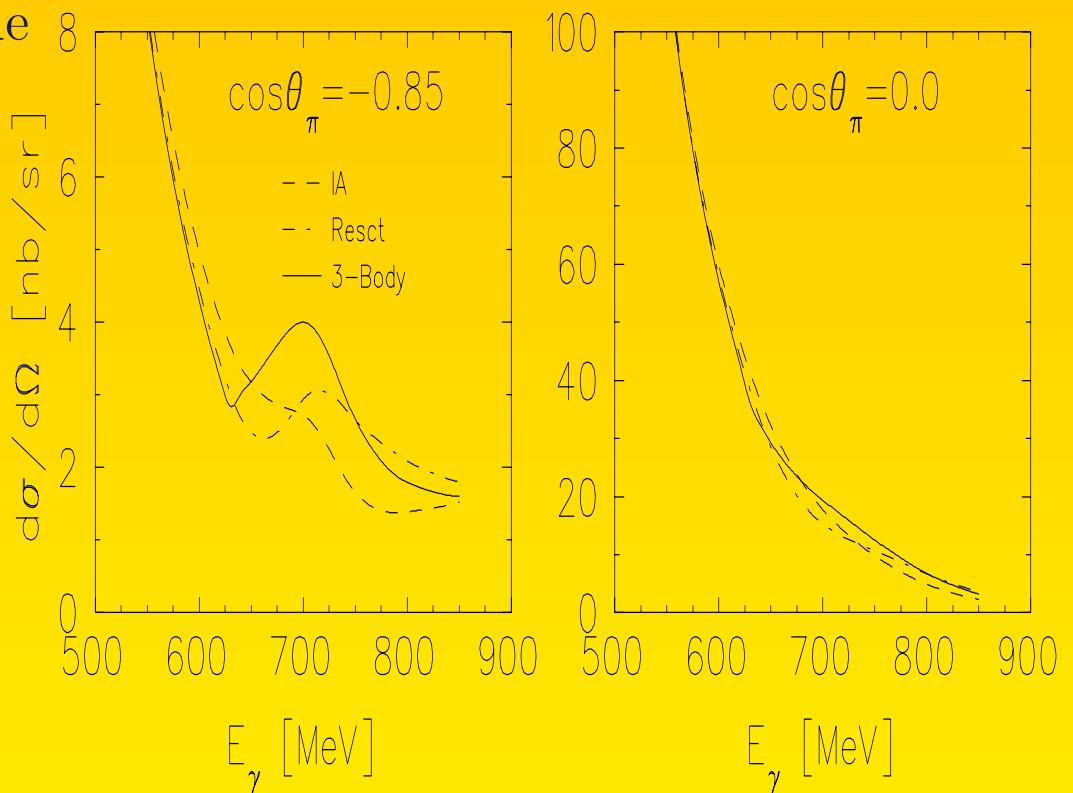
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Physics Motivation: intermediate η rescattering

- Higher order η rescattering might contribute to the magnitude of the structure



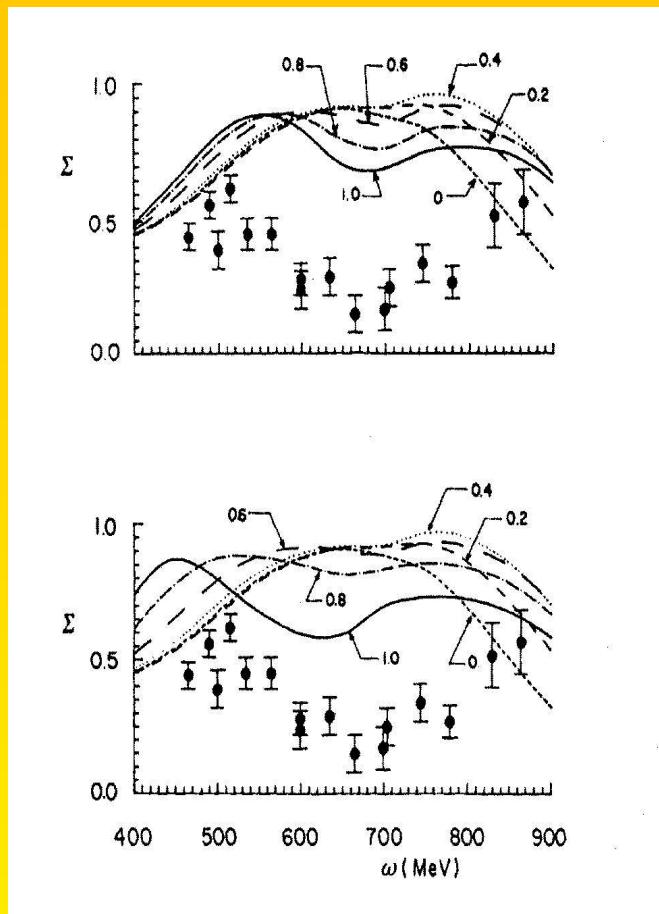
- Production and propagation of the η meson in nuclear matter: related to studies of η -mesic nuclei.



A. Fix, arXiv:nucl-th/0509029 (2005)

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Physics Motivation: intermediate η rescattering

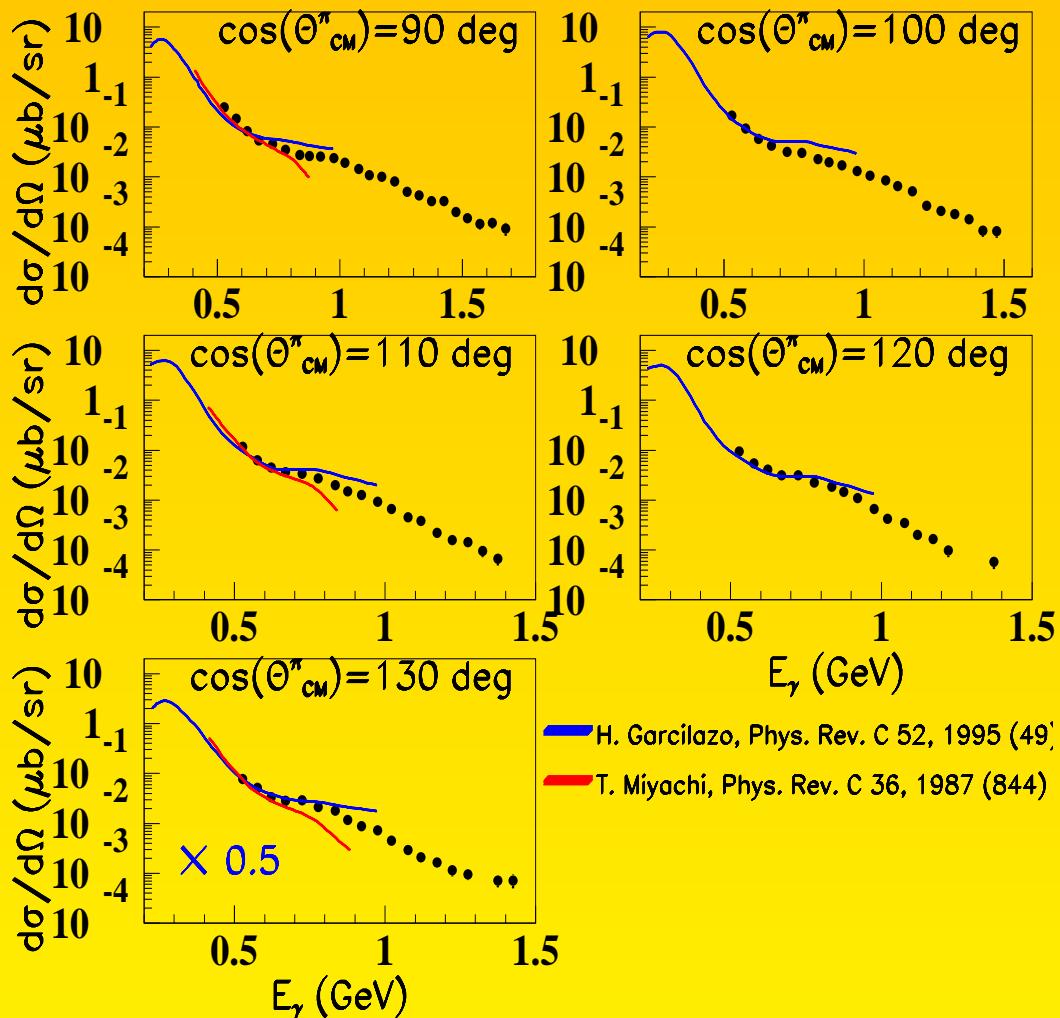


- Previous data: The beam spin asymmetry Σ has a minimum and changes slope at photon beam energies around 0.7 GeV and pion CM angle of 130° .
- Theoretical calculation: The energy dependence of Σ is sensitive to details of the model for the nuclear reaction.

H. Garcilazo and E. Moya de Guerra, Phys. Rev. C49, R601 (1994), and references therein

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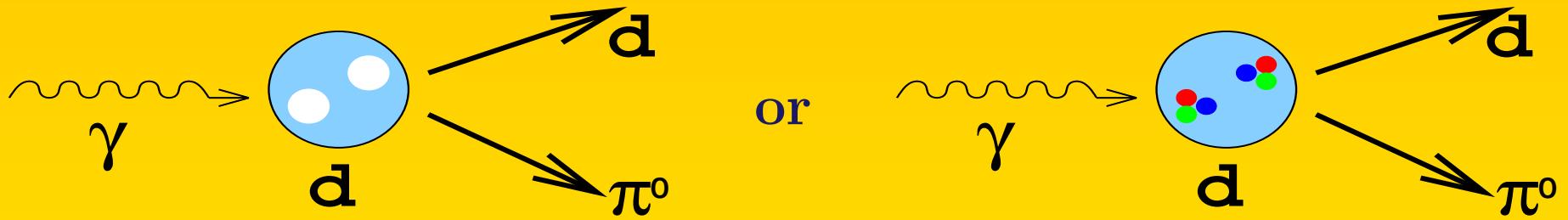
Comparison of CLAS data with traditional meson–nucleon models



- IA provides an adequate description of the data only at small pion CM angles and low beam energies (below 0.6 GeV).
- Pion rescattering amplitude must be taken into account.
- Improved models explain data well up to 0.8 GeV.
- No model predictions exist above 1 GeV.

Physics Motivation: reaction dynamics at moderate t

Effective degrees of freedom



- Moderate momentum transfer: transition between meson-nucleon and quark-gluon degrees of freedom.
- Traditional models fail to describe the unpolarized cross sections.
- Applicability of pQCD highly controversial, but no predictions available from non-perturbative QCD.

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Physics motivation: reaction dynamics at moderate t

- Constituent Counting Rules: at high t and high s , the invariant cross section of an exclusive process of the type $A + B \rightarrow C + D$ has the following asymptotic behavior:

$$\frac{d\sigma}{dt} \sim \frac{1}{s^{n-2}} f(t/s),$$

where n is the total number of the initial and final elementary fields. In the case of coherent pion photoproduction on deuterium $n - 2 = 13$.

- Reduced Nuclear Amplitudes factorization:

$$\mathcal{M}_{\gamma d \rightarrow \pi^0 d}(u, t) = C' f_d(t) \mathcal{M}_{\gamma N \rightarrow \pi^0 N}(u/4, t/4) F_{N_2}(t/4)$$

S.J. Brodsky and G.R. Farrar, Phys. Rev. Lett 31, 1153 (1973)

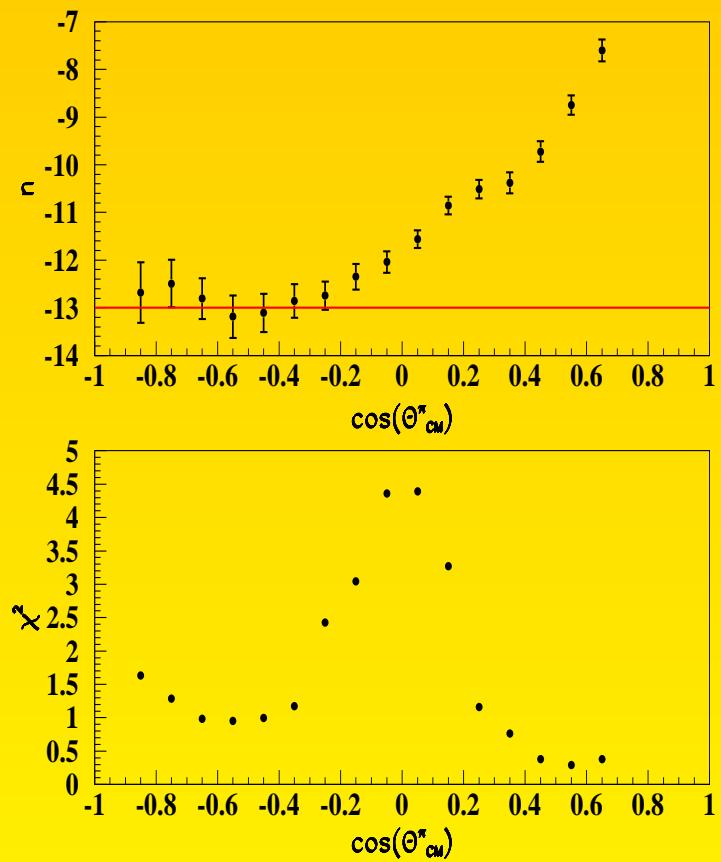
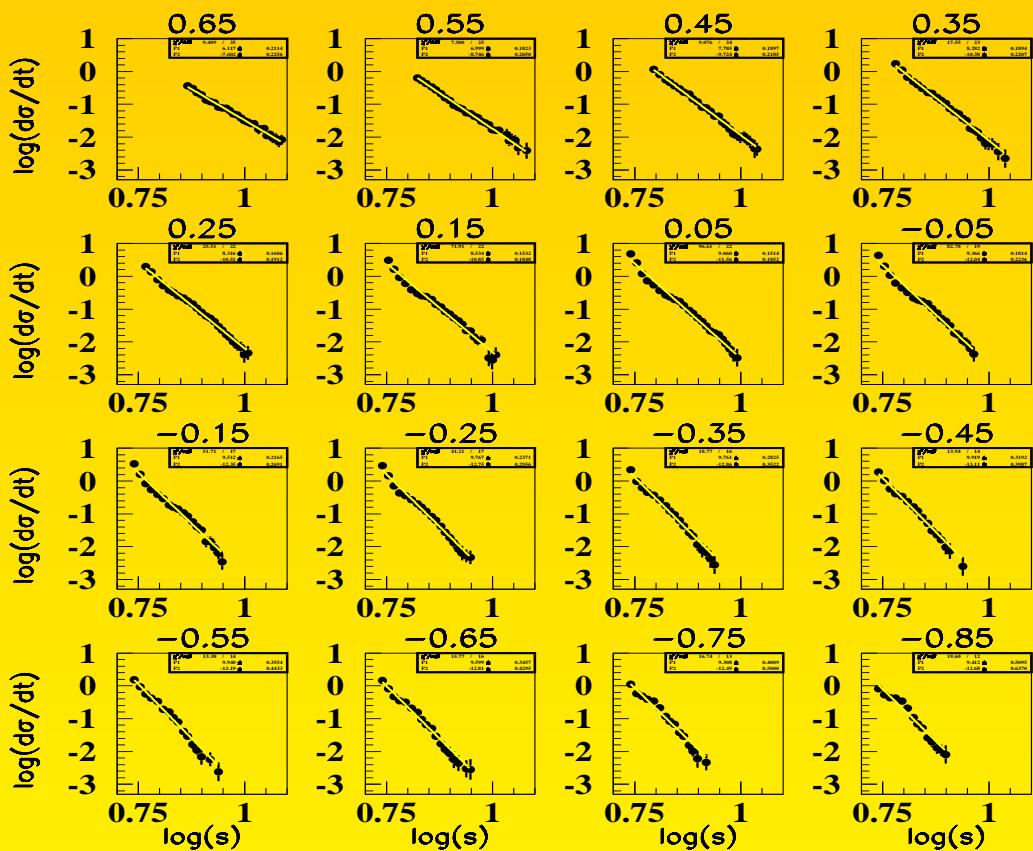
V. Matveev *et al.*, Nuovo Cimento Lett. 7, 719 (1973)

S.J. Brodsky and J.R. Hiller, Phys. Rev. C 28, 475 (1983)

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Reaction dynamics at moderate t

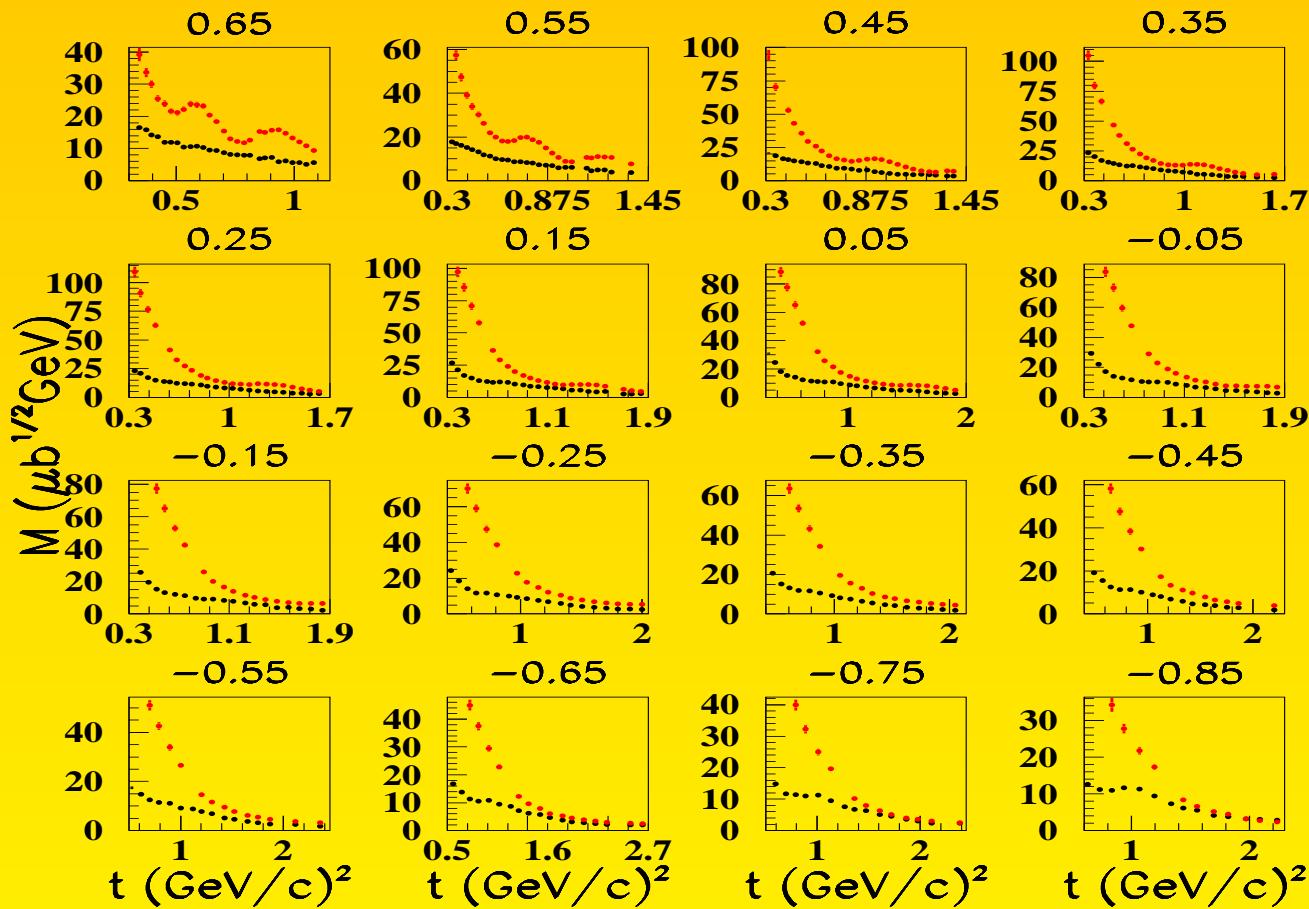
- CLAS data consistent with scaling $\frac{d\sigma}{dt} \sim s^{-n}$, where $n = -13$ at $\cos(\theta_{CM}^\pi) < -0.25$



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Reaction dynamics at moderate t

Reduced–Nuclear–Amplitude predictions



Summary

- At $\cos(\theta_{CM}^\pi) < -0.25$ the CLAS scaled invariant cross sections generally scale as s^{13} . This is in agreement with the results of Meekins *et al.* (Phys. Rev. C60, 052201 (1999)). However, scaling is expected at much higher s and t , at perturbative kinematics.
- Many other exclusive processes show similar variating scaling already at moderate momentum transfer! Scaling seems to have more fundamental origin!
- The CLAS data are consistent with the prediction of the Reduced Nuclear Amplitude approach for the invariant amplitude \mathcal{M} at $E_\gamma > 0.9$ GeV and $\cos(\theta_{CM}^\pi) < -0.65$. Rescattering mechanisms relatively small.

Summary

- Traditional meson-nucleons models describe the cross sections well only up to t of 1 (GeV/c)². Elementary $\gamma N \rightarrow \pi N$, deuteron structure at short distances.
- Around the η -photoproduction threshold $\gamma d \rightarrow \pi^0 d$ is sensitive to intermediate η formation and rescattering through $N^*(1535)$ excitation. The amplitude is enhanced through interference with the background.